A Pulsed Schlieren System for Visualizing Beams from Phased-Array HIFU Applicators

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Abstract. We have assembled a Schlieren system for imaging the beam patterns from HIFU transducers in water to verify the desired beam focusing and direction. It consists of a high power (65 mW) short-pulse (as short as 2 ns) laser emitting at 658 nm, a beam expander/spatial filter, water tank, 400 µm round stop, and a 12-bit CCD camera (1035 x 1317 pixels). The laser is synchronized to the driving electronics of the transducer but its pulse is delayed, effectively freezing of the acoustic wavefronts in the imaged space.

Keywords: Schlieren, Ultrasound Beam Patterns, Pulsed Laser.
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INTRODUCTION

The use of dynamically controlled transducers, particularly phased arrays with electronically variable steering and focusing, is becoming valuable in the proper application of power in high intensity focused ultrasound (HIFU) procedures [1]. Since the phasing and amplitude of the individual elements in the transducer can be a complicated pattern, especially if the focused spot is purposely made larger than a diffraction-limited size in order to more broadly deposit power throughout the local volume, it is important to be able to verify the actual location of the focused spot and the direction of the beam propagation. A Schlieren system allows this in a water-tank environment where diffraction of a laser beam by the ultrasound beam wavefronts produces a pattern on a camera corresponding to the pressure wavefronts.

SCHLIEREN PHYSICS

The Schlieren effect is based upon the principle that pressure fluctuations accompanying the ultrasound beam cause alternating rarefaction and compression of the water density corresponding to the (traveling) positions of the negative and positive pressure wavefronts, leading to changes in the optical index of refraction in the water. When a collimated laser beam is passed through this region, a portion is diffracted away from the original direction by the index variations (Raman-Nath diffraction). After being collected by a lens, the undiffracted portion of the beam is eliminated by a central round opaque stop [2] while the diffracted portion passes around this stop and is imaged onto a CCD camera. This image reveals the pattern of the pressure wavefonts.

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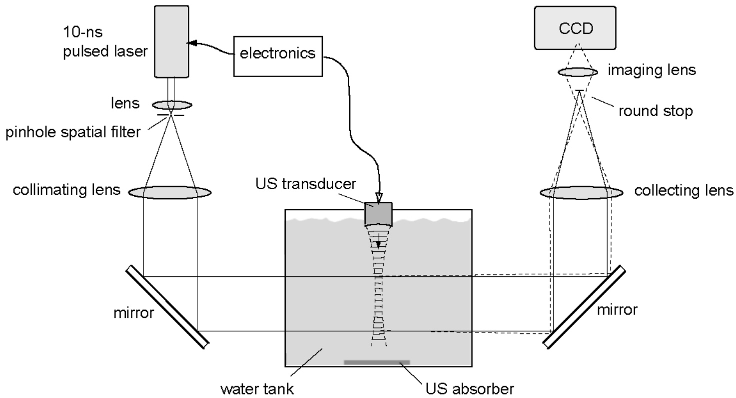

FIGURE 1. A schematic of the layout of the Schlieren system.

SYSTEM COMPONENTS

As shown in Fig. 1, our system in composed of a short-pulse laser whose beam is first passed through a pinhole spatial filter to clean up the profile of the beam, then expanded and collimated to a diameter of about 8 cm for propagation through the path of the ultrasound beam. The transducer to be measured is placed in the water tank and excited by a burst generator whose output is synchronized with the laser pulsing (as described in the next section). Two 45-degree mirrors bend the light path in order to reduce the overall footprint of the system on the table. After passing through the ultrasound beam, the optical beam is collected by a moderate focal length lens, then filtered by the round stop and imaged by another lens onto the CCD camera. Figure 2 is a photograph of the setup on the optical table, and Table 1 gives detailed specifications of each of the system components.

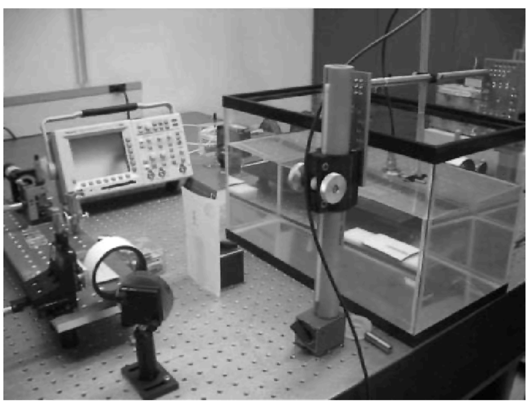

FIGURE 2. Schlieren system assembled on the optical table. The laser and beam-conditioning optics are to the left; the round stop and CCD camera are to the right, out of view behind by the water tank.

TABLE 1. Specifications of the various components in the Schlieren system.

Laser	65 mW, 658 nm semiconductor laser
Laser driver	Variable pulse delay, ~10 ns pulse length
Pinhole spatial filter	25 μm diameter
Collimating and collection lenses	76 mm diameter, 380 mm focal length
Round stop	400 μm diameter
Imaging lens	50 mm focal length, f/1.8
CCD	12-bit, 1035 x 1317 pixels
Minimum acoustic intensity to view	~20 mW/cm^2

SYNCHRONIZATION

In order to freeze the wavefronts at variable distances away from the face of the transducer as the wave propagates, it is necessary to synchronize the pulsing of the laser to the excitation of the transducer [1,2]. Figure 3 is a diagram of the electronic components that we employed in this synchronization method. The burst generator served as the source of the input to the power amplifier driving the transducer, and also as the trigger to a variable time delay. The output of the time delay was fed to a nanosecond pulse generator, which then drove the laser output.

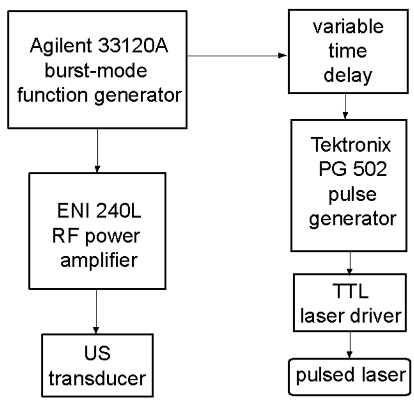

FIGURE 3. Electronic components used in synchronizing the laser pulse to the ultrasound excitation, allowing the position of the visualized wavefronts to be varied.

WAVEFRONT VIEWING

Figure 4 is a Schlieren image of a ruler in the imaging space, giving a measure of the overall beam area that can be imaged—approximately 5.6 cm x 7.1 cm. Figure 5 shows images of the wavefronts produced by a 10-cm diameter transducer excited with a 2-cycle burst centered at 1.5 MHz. The transducer is spherically curved with a focus of 18 cm. By adjusting the time delay of the laser firing, the wavefronts are captured at two distances from the transducer, as the beam converges toward the focus and then as it appears at the focal point.

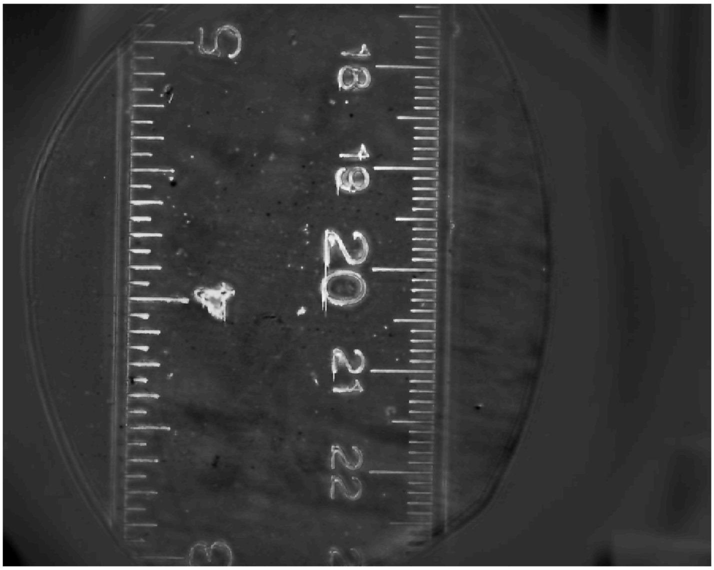

FIGURE 4. A Schlieren view of a ruler, indicating the 5.6 cm x 7.1 cm dimension of the image space.

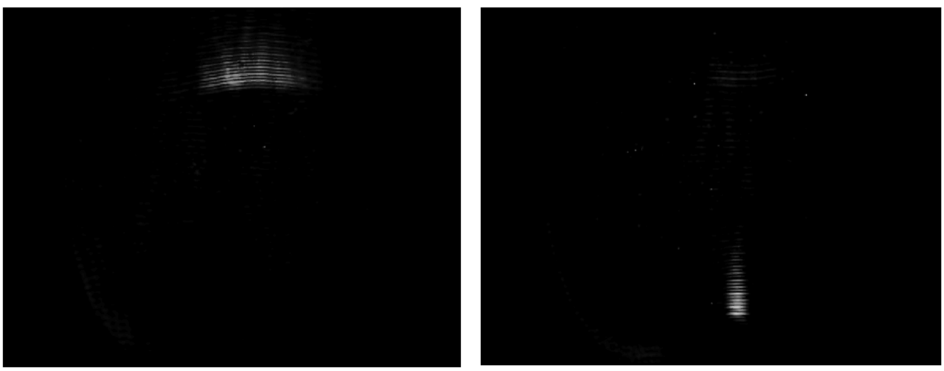

FIGURE 5. The wavefronts produced by a 1.5 MHz transducer excited by a 2-cycle burst as they propagate toward (leftmost figure) and at the focal point (rightmost figure) at a distance of 18 cm.

CONCLUSIONS

We have found that this Schlieren system gives useful information on the direction of beam propagation and location of the focal point. In addition, the ability to freeze the wavefronts yields information about the uniformity and curvature of the wavefronts as well as the effective length of the actual ultrasound output pulse produced. Limitations of this method include the necessity of using an optically transparent propagation medium (such as water) and the need to carefully position the round stop with a micropositioner.

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